Materials Engineering Branch

TIP*

No. 064 Low Cycle Thermal Fatigue Cracking of Solder Joints

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Lead-tin solder joints have performed reliably under thermal cycling conditions at service temperatures ranging from -10°C to +40°C. Continuous exposure to high temperatures (> 100°C) can lead to creep failures and below -170°C, most Pb-Sn solders are embrittled. (Metals Handbook, American Society for Metals, Metals Park, OH, Ninth Edition, Volume 6).

Thermal cycles which extend beyond the -10°C to +40°C range can induce failure by low cycle thermal fatigue if there is a substantial mismatch of coefficient of thermal expansion among the materials comprising the joint. The expected service life is dependent upon: (1) materials involved, (2) joint geometry, (3) extent of temperature excursion, (4) residual stresses present in any joint member and (5) mechanical properties changes, including those resulting from glass transition temperature of organic materials. For example, solder-silicon joints on TIROS solar cell N-strips and arrays with a large differential expansion, failed at 5,000 cycles while copper-solder joints on bifurcated terminals in the same arrays did not fail after 17,000 cycles (Table I).

In most cases, the joint material and geometry are such that thermal stress can be calculated using finite element analysis. However, only rough estimates of service lifetime can be made. Prototype solder joints should be life-tested if extreme temperatures or numerous thermal cycles with a large thermal excursion are contemplated during the service life of the spacecraft.

The next page lists specific examples of this problem.

Low Cycle Thermal Fatigue of Solder

Solder Application	Solder Composition	Approximate T Range (°C) Maximum	Minimum	No. of Cycles	Results
Nimbus & Landsat Arrays • Wire joints • Turret terminals	62.5% Sn 36% Pb 1.5% Ag	60°C	-75°C	4,400	Broken solder joints connecting solar cell strings to the solar array cable
TIROS-N, NOAA & DMSP Q-Boards • Q-Boards • Shunt circuits	62.5% Sn 36% Pb 1.5% Ag 70% Sn 30% Pb	80°C 75°C	-85°C -40°C	4,569 17,000	Terminal fatigue cracking of solar cell N-strip solder joints No fatigue damage in solder
Solder/Silicon & Solder/ Copper Samples	62.5% Sn 36% Pb 1.5% Ag	83°C	-90°C	900 13,323	Solder cracked on silicon Solder did not crack on copper
Landsat D' Diode Array • Turret terminals	70% Sn 30% Pb	70°C	-75°C	7,800	No fatigue damage in solder
Air Force/ITT Solder Cracking Study • PC board terminations	50% Sn 50% Pb 63% Sn 37% Pb 70% Sn 30% Pb 40% Sn 60% Pb	150°C	-65°C	800	All solder joints developed fatigue cracks